Chapter 5

Establishing a Vigorous Nursery Crop: Bed Preparation, Seed Sowing, and Early Seedling Growth

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Abstract

Many aspects of preparing a production nursery bed, such as correcting drainage problems, eliminating disease potential, and maintaining fertility and pH, are specific to site history and soil properties. Efficiency of field use is a major concern in designing a nursery and should be considered when aligning beds and installing irrigation systems. Sowing should be done in spring, commonly in April or May, after soil temperatures at the 10-cm (4-in.) depth reach 10°C. Though seeders commonly used tend to produce clumpy distributions, adverse effects on seedling quality and quantity are reduced at low densities. Both seedling quality and cost are affected by seedbed density; therefore, great care must be exercised in prescribing densities. Sowing formulas must consider the desired seedling density as well as expected yields and various aspects of seed quality and quantity. Expected tree, yield, and damage percents, derived from experience, should be reevaluated annually. Proper care and tending after sowing are critical for obtaining high tree percents. Diseases, birds, and weather are the most common causes of loss, and preventive measures should be taken whenever possible.

5.1 Introduction

As with most endeavors, getting off on the right foot is important in growing a quality nursery crop. Care taken in ground preparation, sowing, and early seedbed monitoring will result in better drainage and fewer disease problems as well as more and better seedlings at harvest. Early and thorough planning will provide the flexibility needed for nursery personnel to cope with changing conditions yet maintain quality.

This chapter presents procedures for bed preparation, seed sowing, and early seedling maintenance which are based on current practice in the Northwest and on the available literature. Universal practices are simply mentioned. Those that are controversial or that vary greatly from nursery to nursery are examined more closely. Alternatives are discussed and, if warranted, recommendations made. Theory and practice in many important areas such as fertilization, weed control, and seed properties as they relate to sowing and early growth are not covered extensively because these topics are fully addressed by others in chapters 7, 18, and 4, respectively, of this volume. Further information on many subjects addressed here also is discussed by Armson and Sadreika [2] and Aldhous [1].

Each step in establishing a vigorous crop has a number of alternative approaches. When possible, several alternatives and their pros and cons are described. The lists, however, are not exhaustive and other possibilities exist. A good rule of thumb when weighing alternatives is to ask questions such as:

- How much will a given treatment cost?
- What is the expected outcome of an alternative treatment?
- What extra cost or loss in seedling quality can be expected from **not** following a prescribed treatment or preferred alternative?
- Is this cost or loss acceptable?

Alternatives and combinations of alternatives are many. Each nursery manager must ask the above questions and reach decisions based on his or her own situation. Adherence to sound principles and proper timing will result in rapid establishment and growth of seedlings.

5.2 Production-Area Development

Past land use and present condition are among the most important factors to consider when establishing a new nursery and preparing it for sowing.

5.2.1 Previous land use

First, ascertain what was growing on the site during the last 5 years. If the land was in agricultural use, determine whether any of the previous crops could have become infested with diseases or insects that also attack crop-tree species or whether weeds present are difficult to control. If diseases or pests are suspected, identify the problem by soil assay or insect trap-

In Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

ping and take appropriate management measures before a nursery crop is sown. If previous crops are unknown or assays impractical, presowing soil fumigation is good insurance because it will remove most pathogenic fungi and weeds. It may, however, negatively affect beneficial soil organisms such as mycorrhizae and bacteria [6], and it is very expensive ($ 1,000 to $1,500/acre) (see chapters 19 and 20, this volume). Once pests have been identified, specific treatments can be applied that cost less and maintain beneficial soil microorganisms.

Hard-coated weeds such as clover and vetch are not killed by fumigation. Summer fallow with tillage and irrigation will remove these weeds best. When seeds sprout, allow them to grow rapidly until the first true leaves appear; then till in. After each tilling, a new crop will appear, so the sequence must be repeated. Irrigation helps ensure rapid growth during July and August so that as many "crops" of weeds as possible can be grown and killed during a single summer. If time does not permit a summer fallow, an extensive herbicide schedule, hand weeding, or both will control the problem, but some seedlings will be damaged.

Former forest sites pose some additional problems. Clearing, removing debris, and leveling can be expensive and time consuming. Tree roots and, in many cases, rocks complicate the task: seeds sown on a rock or root have little chance of developing into acceptable seedlings. However, seedling diseases usually are less prevalent, weed problems generally are fewer, and beneficial mycorrhizae-forming fungi often are endemic.

5.2.2 Leveling land and orienting beds

Once cleared, a field must be leveled and sloped. If it is already reasonably level, with a slope of 2 to 3 % [10], adequate finish leveling may be accomplished with a land plane. However, where drainage is restricted or frost pockets are formed by natural contours, more severe measures are needed (see chapters 6 and 13, this volume).

Depending on depth of the cuts and fills, removing topsoil and storing it for return after leveling may be the first step. As with all major projects requiring heavy equipment, land leveling should be done when the soil is driest to minimize the chance of massive compaction [23]. If possible and practical, fields should be leveled and sloped so that the least amount of soil is moved. Careful attention to this aspect will save money and minimize compaction. Desired slope also depends on soil characteristics. Sandy soils require less slope than heavier soils. increased slope favors bed erosion in sandy soil but aids surface drainage in finer textured soil [14]. Fields can be tiled for supplemental drainage before final leveling and sloping.

Bed orientation, important to ease of operation and seedling growth, should be considered **before** final slope and road positions are planned. Where no additional sloping is necessary on a newly acquired field, orient beds to run perpendicular to the land contour for maximum drainage. Where contours must be drastically changed, consider the possible advantages and disadvantages of east-west or north-south orientation. In an area where lifting is restricted due to frozen ground, orienting beds in a north-south direction will facilitate early thawing by the morning sun [1]-and thereby lifting. East-west orientation increases the possibility of sunscald in the summer and will cause growth differentials across the bed due to shading [unpubl. data, 22]; where frozen soil is not a problem, east-west orientation can produce acceptable results.

5.2.3 Laying out irrigation and road systems

Once bed orientation has been determined, irrigation and road systems must be designed and installed. Bed lengths in Northwest nurseries range from 76.25 to 152.5 m (250 to 500 ft) (OSU Nursery Survey; see chapter 1, this volume) under normal circumstances because a pressure drop can occur in longer irrigation lines. At the Forest Service Nursery in Medford, Oregon, beds are 244 m (800 ft) long, but the possible pressure drop is compensated for by starting the lateral pipes at the top of the slope, adding the downhill rush of the water to the line pressure.

Nozzle size, sprinkler pressure, and spacing of lateral lines and of sprinklers on laterals all are important to uniform delivery and application of water. For uniform water application in winds up to 5 mph, sprinklers should be placed so that the longest of the two distances in rectangular spacing (the distance between sprinklers either on adjacent laterals or on the same lateral) is 60% of the no-wind diameter (see manufacturer's specification) of the sprinkler used, and so that the sum of the two spacings is not more than 105% of that diameter [16, 18]. For example (Fig. 1), if sprinklers have a no-wind diameter (C) of 20.4 m (67 ft), the largest spacing in one direction could be 60% of 20.4 m (67 ft), or 12.2 m (40.2 ft). Therefore, the distance between sprinklers on the adjacent laterals (B) is 12.2 m. Then, solving the formula for A:

105% C = A + B

1.05(67) = A + 40

A= ~ 9m (~ 30 ft)

Sprinkler-pattern diameter should be increased or spacing along the lateral decreased where higher wind speeds are expected. No additional uniformity is achieved with triangular, rather than rectangular, spacing [18]. Water-droplet size, a result of nozzle size and pressure, can greatly influence crusting of the soil surface. Therefore, during germination, a smaller nozzle size may be desirable to reduce crusting [16]. (For more information on irrigation and nursery-site layout, see chapters 11 and 2 respectively.)

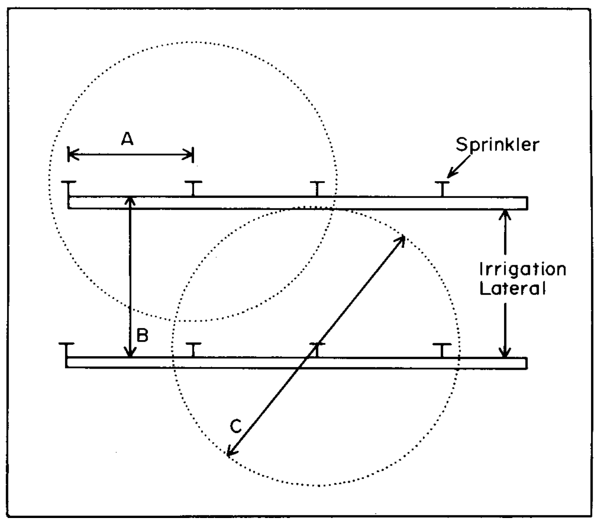

Figure 1. Correct sprinkler distance for uniform water distribution in a typical nursery section. A Is the distance between sprinklers along the same Irrigation line, B the distance between adjacent irrigation lines, and C the sprinkler-pattern diameter. If C = 67 ft, then A or B, whichever is larger, should not exceed 0.6 x 67, or 40 ft, and A + B should not exceed 1.05 x 67, or 70 ft.

5.2.4 Field efficiency

Field efficiency (the amount of area growing trees divided by the amount of area cultivated in a given field) is primarily determined by irrigation-system design. Distance between irrigation laterals is a major component affecting efficient land use within the production field. Once a fixed irrigation system is installed, it is difficult, if not impossible, to improve field efficiency because the area saved in narrower paths will result in wider unused strips along irrigation lines. In the Northwest, various combinations of bed and tractor-path widths, numbers of seedling rows per bed, and distances between irrigation lines are used (Table 1), resulting in field efficiencies ranging from 55 to 71%; 2/3 of the nurseries report efficiencies of 58 to 63%.

Table 1. Factors affecting field efficiency (OSU Nursery Survey).

	Highest	Lowest	Most common
Bed width, m (in.)	1.27 (50)	1.07 (42)	1.22 (48)
Path width, m (in.)	0.76 (30)	0.53 (21)	0.61 (24)
Rows of seedlings/bed[1]	8	7	8
Beds between irrigation lines	9	5	6
Distance between irrigation lines, m (ft)	15.9 (52)	9.15 (30)	12.2 (40)

[1]For 2+0 beds.

Width of tractor paths also is important for calculating efficiency. As path width increases from a theoretical minimum of one tractor tire width (38 cm, or 15 in.) to the practical maximum of two tractor-tire widths (76 cm, or 30 in.), field efficiency drops, and the required distance between irrigation lines increases. Because tractor operations can be difficult when paths are too narrow, most nurseries compromise with path widths of 61 cm (24 in.). A typical nursery section (that distance between two irrigation laterals) (Fig. 2) would include six beds, each 122 cm (48 in.) wide, with 61-cm (24-in.) tractor paths and irrigation lines 12.2 m (40 ft) apart (OSU Nursery Survey). Such an arrangement would result in 60% field efficiency.

5.3 Field Preparation

5.3.1 Preparing the soil

After the field has been sloped and leveled and once road and irrigation systems have been installed, there is little difference in the steps necessary to cultivate and prepare beds in a new nursery field or one used many times before. In both situations, examine the physical and chemical properties of the soil.

Compaction is the most commonly cited soil physical problem (see chapters 6 and 29, this volume). If compaction is known or suspected, deep subsoiling during the late fall is recommended to improve drainage. A green manure crop that has a fibrous root system can improve soil physical properties and may increase organic matter (see chapters 9 and 10, this volume).

Fertility and pH are important soil chemical properties (see chapters 7 and 8, this volume). Soil tests for phosphorus, potassium, calcium, and magnesium provide a basic inventory of mineral nutrients. If these elements are significantly deficient, the appropriate fertilizer should be added before bed forming. For optimum conifer growth, pH should be kept between 5 and 6. The pH is best adjusted during a fall fallow period so that the reaction of amendments with the soil will have been effected before sowing. Sulfur is used to lower soil pH and lime to raise it.

Soil is most often fumigated to remove weeds or pathogens in fall (OSU Nursery Survey). Methyl bromide/chloropicrin (67% / 33%) is preferred in the U.S. because of its proven effectiveness. Law prohibits its use in Canada (see chapter 19, this volume). Note that methyl bromide reacts with sulfur; therefore, if sulfur is being used to reduce pH, it should be applied after fumigation [pers. commun., 24].

Figure 2. Typical nursery beds within sections. Note raised beds and tractor-path width.

Following fumigation, the field is left fallow over winter. In spring, when the soil is dry enough to work, cultivation for sowing should begin. What implements are used and in what order depends mainly on soil texture. In any event, the objective is to prepare the field so that a bed former can be used to produce level, even seedbeds. Care should be taken not to mix unfumigated soil from below or from edge areas into the fumigated field. Nurseries with sandier soil usually require minimal presowing soil preparation. Before final presowing cultivation, fertilizer can be spread and incorporated into the soil (see chapter 7, this volume). Final preparation should leave the soil fluffed and mixed, ready for bed shaping.

5.3.2 Marking and forming seedbeds

Some nurseries, especially those with inexperienced tractor drivers, have difficulty getting beds formed straight and at the proper intervals between irrigation lines. Most nurseries have adopted some homemade equipment to remedy this situation. Many possibilities exist. With an experienced tractor driver and relatively short beds, "eyeballing" the beds works surprisingly well. Some nurseries run string lines to get straight beds; others rely on tractor-mounted bed markers.

A method that uses a bed marker and the irrigation line as a reference point can be adapted wherever a fixed irrigation system exists. First, irrigation lines are positioned in the field. Their proper placement is important and should be done with surveying equipment so that the distance between any two lines is constant. To form the first two beds along the outside of the nursery section, next to the laterals, a chain is suspended from a bar attached to the front of the tractor at the proper distance from the outside wheel; while driving, the tractor operator keeps the chain over the irrigation line and thereby creates a straight bed. A bed marker, which need consist only of a wheel on a pipe, is mounted on the side of the tractor opposite to that with the irrigation tracing chain; it marks where the tractor wheel should run for the next bed, usually about 1.8 m (6 ft) away, depending on the path width desired. Many other systems that accomplish the same results exist. An accurate but expensive method employs a tractor equipped with a laser-tracking device and a laser-emitting target; however, this kind of precision is not necessary for growing quality seedlings.

Two general types of bed formers are commonly in use in the Northwest. One type simply moves soil from the tractor path onto the raised bed and levels off the bed surface. This type, often homemade, can be mounted behind or under the tractor; Whitfield Manufacturing Co. (Mableton, Georgia) makes one commercially that works on this principle. A second type combines final tilling and bed forming by attaching a bed shaper to the back of a 1.8-m (6-ft) rototiller or roterra. This second type requires less field preparation before bed shaping; but the rototiller may produce a soil layer that is compacted, restricting drainage, and should therefore be avoided on heavier soils (see chapter 6, this volume).

Beds, however shaped and formed, are generally raised between 7.5 to 15 cm (3 to 6 in.) above the tractor paths to increase drainage and promote warming of the seedbed (OSU Nursery Survey). Both an increased germination rate and more rapid root growth can be expected. Beware of deep tractor paths, however—they can cause problems during the second growing season. Implements such as individual-bed fertilizer spreaders and even tractor bellies can scrape the tops of tall 2+0 seedlings. The resultant damage can reduce the number of shippable seedlings (seedlings that pass all standards for both size and form) and may promote disease development.

5.4 Sowing

Once the previous sequence of steps has been followed, the field is ready for sowing. Successful sowing depends on type of seeder, sowing date and depth, bed density, and sowing formula.

5.4.1 Seeders

In Northwest nurseries, the two most common seeders are the Øyjörd seeder (manufactured by Love Co., Garfield, Washington) and the Wind River seed drill (OSU Nursery Survey). According to the Survey, neither is wholly satisfactory—the largest complaint is clumpy seed distribution, a problem that no commercially available seeder has as yet solved. A comparison of ease of operation of these seeders and the Stan Hay found the Øyjörd to be slightly superior (Table 2) [13].

Table 2. Summary of operational seeder characteristics [adapted from 13].

	0yjörd	Stan Hay	Wind River
Ease of adjustment	Excellent	Poor	Fair
Range of adjustment	Adequate	Adequate	Adequate
Ease of calibration	Excellent	Poor	Fair
Clean out	Excellent	Poor	Fair
Seed damage	Low	Moderate	Low
Range of travel speeds	Adequate	Limited	Adequate
Variation with speed	Low	High	Low
Number of hoppers	One	One/row	One with one pocket/row
Depth control	Good	Good	Good
Seed covering	Good	Good	Good
Construction	Good	Good	Good

5.4.2 Sowing date

Regardless of seeder chosen, deciding when to sow is important and depends on several factors, some of which are related to seedling growth and some of which are wholly operational. Sorensen [19] found that Douglas-fir *[Pseudotsuga menziesii* (Mirb.) Franco] sown as germinants set bud earlier and had a longer shoot-elongation period when sown earlier. Each day of earlier sowing between April 23 and May 12 increased height of 1+0 seedlings by about 0.5 mm. Differences in budset and height persisted through the second year, indicating that early sowing can increase seedling size.

To attain germinants in the nursery by April 23, seed must be sown in the cold, wet nursery soil April 1 or before. This is often impractical because the soil is unworkable. Furthermore, germination is slower in cold, wet soil, creating a situation where preemergence damping-off can reduce total germination [20]. Data from the OSU Nursery Survey indicate that most sowing in the Northwest is done between mid-April and early June. Sowing is best done as early as possible after average soil temperature at the 10-cm (4-in.) depth exceeds 10°C. In Oregon's Willamette Valley, this usually occurs in early to mid-April.

Although spring sowing is the norm, fall sowing can provide natural stratification and has been shown to produce excellent seedlings. The advantages are outweighed, however, by the disadvantages. Fall-sown beds must be protected from rodents and birds, should be mulched to prevent frost heaving, and may be lost to early spring frosts. Bed preparation and nursery-space availability also may be problems [15].

5.4.3 Sowing depth

Sowing depth is crucial to producing a uniform bed of seedlings. As with many other seeding parameters, the accuracy with which a selected depth can be achieved depends on uniformity of the prepared seedbed and soil properties. If a bed lacks a level, flat top, then sowing depth will vary greatly from row to row and even along a given row. This variation can lessen germination, retard growth, and reduce crop uniformity. Experiments have shown how germination can vary with sowing depth for slash pine (*Pinus elliottii* Engelm.) (Fig. 3) [17]. Similar results can be expected with Northwest species.

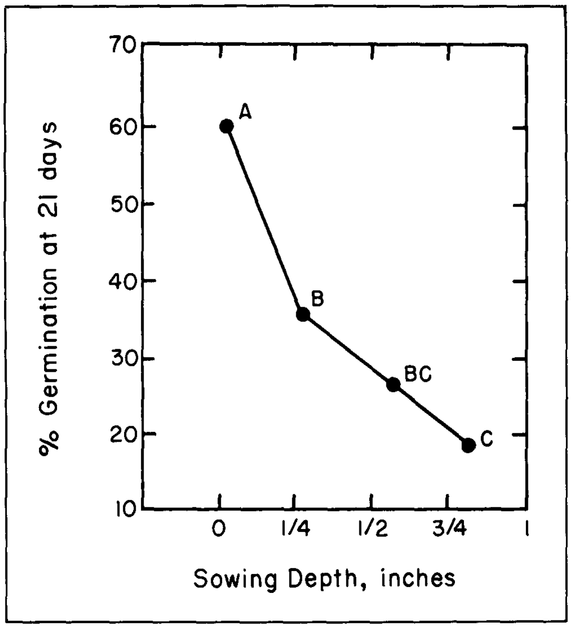

Figure 3. Effect of sowing depth on speed of germination of slash pine seedlings. Points followed by the same letter do not differ significantly at the 95% confidence level, according to Duncan's new multiple range test (adapted from [17]).

Best germination is obtained by sowing seed only as deep as necessary to cover it and prevent erosion or birds from removing it. Reported sowing depths for Douglas-fir and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) vary from "just covered" to 1.25 cm (1/2 in.): the most commonly used depths range from 0.31 to 0.62 cm (1/8 to 1/4 in.) (OSU Nursery Survey). In the Canadian nurseries surveyed, seed was surface planted and then covered with a 1/4 inch of sand. Seedbeds are not mulched with water-holding material at the time of sowing in the Northwest (OSU Nursery Survey).

5.4.4 Seedbed density

In recent years, nurseries have responded to the research results on seedbed density and spacing by decreasing the number of seed sown per square meter. The density at which a nursery chooses to sow depends on the seedling characteristics desired at harvest and the economics of seedbed use.

Experiments have shown that increasing bed density is closely correlated with decreasing stem diameter and dry weights in Douglas-fir [9, 11, 25] and three western pine species [4]; it has been negatively correlated with height growth in some experiments [9] but not in others [11]. When outplanting results from seedlings grown at various densities were compared, survival did not differ significantly, but seedlings initially grown at lower densities (108 to 215 seedlings/m^2, or 10 to 20 seedlings/ft^2) grew taller than those grown at higher densities [11] (see also chapter 15, this volume).

Logic dictates that seedling spacing within a row should be as uniform as possible for optimum growth. However, many seeders produce a clumpy distribution. At the lower densities commonly used (108 to 215 seedlings/m^2, or 10 to 20/ft^2), the range of spacing created with a Wind River drill did not affect either stem diameter or shoot:root ratio of seedlings [3]. Similar research comparing morphology of seedlings grown in hand-thinned, uniformly spaced beds vs. those grown in operationally sown beds of the same average density showed that spacing did not affect seedling caliper, whereas density did [unpubl. data, 22].

To determine sowing density (the number of viable seed sown per square meter to achieve a given density at lifting), the nursery manager must know the intended diameter specification of a shippable tree at lifting and the diameter distribution of seedlings grown at various densities in the nursery. The manager must estimate tree percent (the number of trees in a nursery bed at lifting relative to the number of viable seed sown) and then must designate an acceptable yield percent (the percentage of trees meeting a specific size criterion, regardless of form). On the basis of yield percent, a density is chosen which will give the maximum number of shippable seedlings per square meter at the lowest cost. Yield percent is an important economic factor not only because seed is becoming more expensive, but because lifting and handling many more seedlings than are shipped can also be expensive.

Bunting [5] gives an excellent account of the dilemma faced when choosing a bed density:

> "The choice of which density to grow your seedlings at is always a compromise. It would be nice to be able to grow the beds thin enough so that there would be no built in cull factor, on the other hand, the thinner you grow your beds the fewer shippable trees you produce per acre and hence production costs go up. When you increase densities to try and maximize the number of shippable trees you will produce per acre you increase your cull percentage and your lifting costs. Since lifting and shipping costs can be greater than the cost of producing the stock, this is no small consideration."

A good way to choose the correct growing density (density in a bed at lifting, usually for 2+0 seedlings; sowing density x tree percent) for a specific diameter limit and a given nursery is to construct a set of curves similar to those in Figure 4 for 2+0 Douglas-fir [unpubl. data, 22]. It is important to remember that a yield percent of 75 does not mean that 75% of the seedlings will be shippable, only that 75% will meet the diameter standard. Of those meeting the diameter standard, a certain percentage (the damage percent) will exhibit some defect such as root damage, multiple tops, or disease that will make them undesirable. The percentage of the crop that is shippable

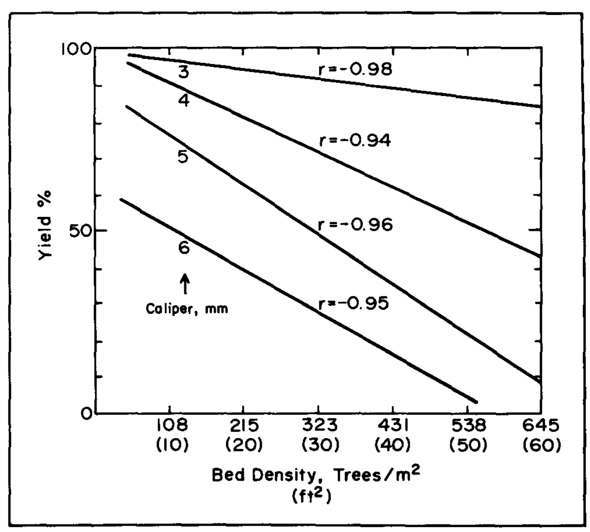

Figure 4. Yield percent for various caliper standards and bed densities for 2+0 seedlings [unpubl. data, 22].

(shippable percent) is thus calculated as yield percent x (1 — damage percent). Barring a large loss to disease or insects, a damage estimate of 5 to 10% is probably conservative when calculating sowing formulas. When possible, this factor should be based on past experience with the nursery in question.

A bed density is chosen based on seedling specification (e.g., 4-mm caliper) and on an acceptable compromise between maximum yield percent and maximum number of seedlings per square meter. In the Northwest, growing densities vary by stock type and range as follows (OSU Nursery Survey):

Stock type	Seedlings/m^2 (ft^2)
2+0	161-323 (15-30)
2+0 for 2+1	376-538 (35-50)
1+0 for 1+1	538-753 (50-70)

5.4.5 Sowing formula

Before seed can be sown, a formula must be employed that calculates the amount of seed necessary to sow to produce the desired number and size of seedlings. In general, all sowing formulas have the same basic form; they differ radically, however, in the number and refinement of the factors used in their calculation.

Some nurseries use a "nursery factor" that is a combination of all possible causes of seedling loss between germination and shipping. However, as a composite, it tells the grower little about what specific problem is causing the loss. Other nurseries have been compiling data for many years and have factors for correcting sowing formulas based on nursery field, species, and sometimes even field-by-species interaction. For a new nursery or one that does not want or cannot afford to compile very specific data, the seed and nursery factors discussed in the following two sections (5.4.5.1 and 5.4.5.2) should allow nursery personnel to track seedling survival and yields with minimum effort and to pinpoint problem areas for improvement.

5.4.5.1 Seed factors

Before any sowing formula can be used, the nursery manager must know the quality of the seedlot intended for sowing. Most nurseries will obtain the data necessary from an independent seed-testing laboratory, although some prefer to perform the tests themselves (see chapter 4, this volume).

In any case, seedlot quality is determined on the basis of three major factors. Seed purity percent is the percentage of the seedlot, by weight, that is seed, not debris. A high percentage (25%) of debris can cause seeders to plug and reduce seeding accuracy. Seed germination percent is the percentage of the total number of seed tested that germinate after a standard treatment and set period of time in the laboratory. This factor can vary greatly from one lot of a given species to another. Estimates from past experience can be very inaccurate and should only be used as a last resort. Furthermore, results from laboratory and field germination often do not agree, probably due to variation in stratification length and, of course, germination conditions. If no better data are available, however, laboratory germination is probably a reasonable approximation of field germination. A 1,000 seed weight is determined by weighing 1,000 seeds plus the accompanying debris. The pure, live seed (the expected number of germinants to be produced) per kilogram can then be calculated. The difference between laboratory and field germination, if known, can be used to modify the pure, live seed calculation.

Seed is wet stratified before sowing for periods varying from 1 week to 4 months depending on species (see chapter 4, this volume) and surface dried just before sowing. The seed is spread on screens to air dry until surface moisture no longer holds seeds together and they do not stick to the hand. Drying allows the seed to flow smoothly through the drill and reduces clumping. No seed in the Northwest is treated with bird repellent or fungicide before sowing (OSU Nursery Survey).

5.4.5.2 Nursery factors

Nursery factors affecting the sowing formula include tree, yield, and shippable percents, bed density, and number of seedlings ordered.

Tree percent depends heavily on cultural practices and environmental influences. Refinement can be made by calculating this factor at each inventory (e.g., 1 +0 tree percent, summer 2 +0 tree percent, and fall 2 +0 tree percent) and using these numbers to project final 2+0 bed density and tree percent. For example, a higher than expected 1 +0 tree percent may indicate that trees should be thinned to obtain the lower density needed for the expected yield percent. Calculating intermediate tree percents may also allow the nursery manager to pinpoint the time of loss and, thereby, the cause. Cultural practices can then be changed to minimize losses.

Any tree percent used in the sowing formula is, at best, an average of many years of experience and, at worst, a conservative educated guess. Owston and Stein [15] reported a range of 25 to 77% for Douglas-fir (unweighted average for 18 nurseries, 51%); similar tree percents (48 to 80) are reported for ponderosa pine [12]. Most Northwest nurseries use a tree percent of 60 to 80 for Douglas-fir (OSU Nursery Survey).

However, as previously noted, certain size and form criteria must be met for seedlings to be considered shippable. Seedlings present in the tree percent that meet the size criterion make up the yield percent: of these, some will be lost to the damage percent. The remainder are the shippable percent. As discussed earlier, yield percent varies with bed density. Selecting an economically feasible yield percent for a given size criterion also sets the best bed density for that seedlot (Fig. 4).

To complete the sowing calculation, only the number of seedlings ordered by the customer is needed.

5.4.5.3 Calculating the sowing formula

Once seed and nursery factors have been determined, calculating the sowing formula is easy:

(1) Pure, live seed per kilogram (PLS/kg) =
(germination %/100) x (purity %/100) x (1,000 g/1,000 seed weight)

(2) Number of shippable seedlings produced per kilogram of seed =
PLS/kg x (tree %/100) x (yield %/100) x (shippable %/100)

(3) Kilograms of seed required =
(Number of seedlings ordered)/(number of seedlings/kg)

(4) Meters of nursery space required =
[(Kilograms of seed required) x (PLS/kg) x (tree %/100)]/bed density

For example, let's assume we received an order for 1,000,000 Douglas-fir seedlings. Seed test results are 83% germination, 98% purity, and 1,000 seed weight of 11.6 g. Pure, live seed per kilogram can then be calculated:

(83/100) x (98/100) x (1,000/11.6)= 70,120

From past records, we know our tree percent is 80 and our shippable percent 86. Seedlings must have a 4-mm caliper to meet the size criterion, and an economic analysis indicates we need a yield percent of 87.5% to balance packing and bed-area costs. Number of seedlings produced per kilogram of seed is calculated:

70,120 x (80/100) x (87.5/100) x (86/100) = 42,212

Thus, the kilograms of seed required would be

1,000,000/42,212 = 23.69

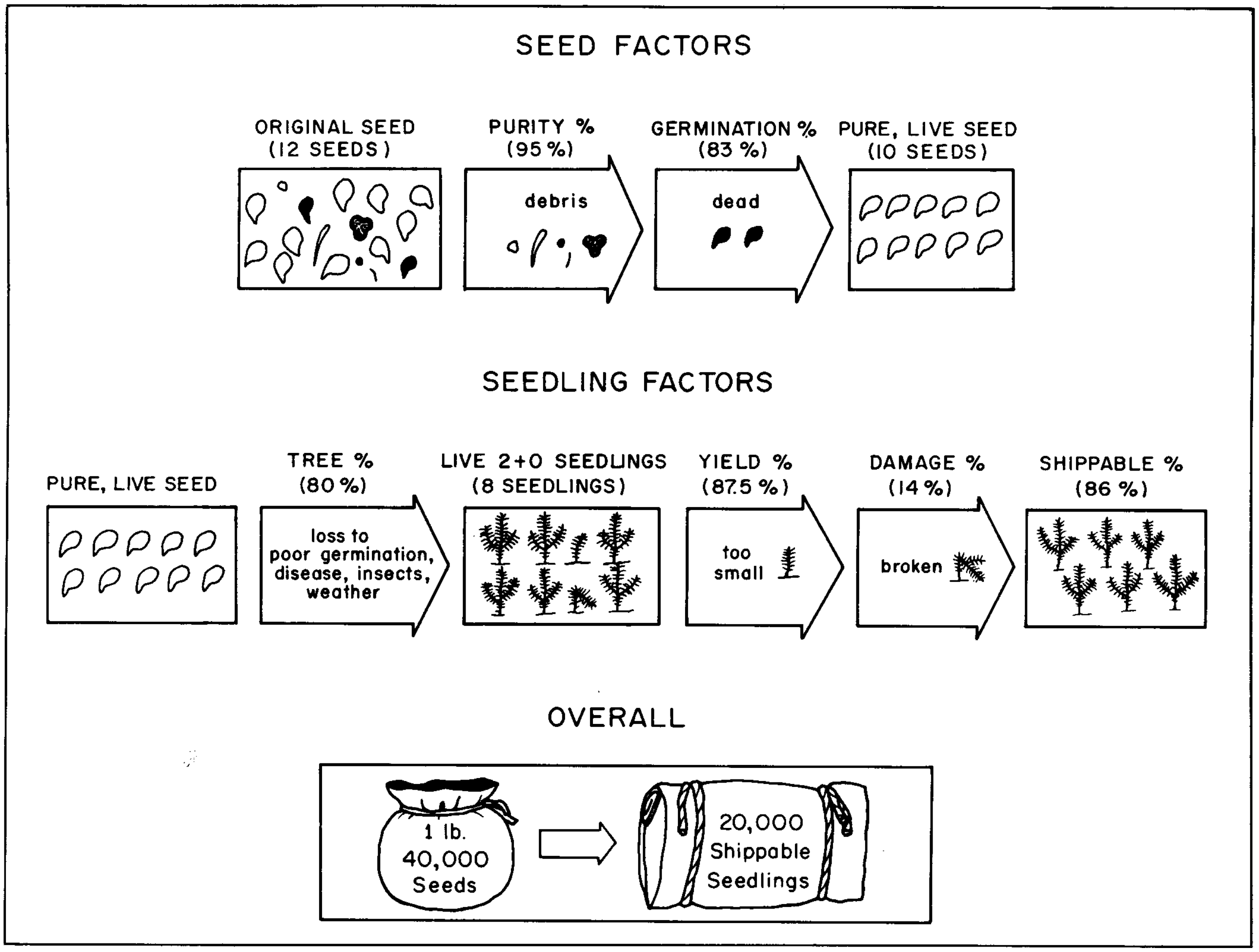

Figure 5. Fate of seed and seedlings in the nursery.

From Figure 4, we determine that the best density at which to grow our seedlings would be 250 seedlings/m^2. In that case, bed space required (in square meters) can be calculated:

[(23.7) x (70,120) x (80/100)]/250 = 5,318

Figure 5 demonstrates how seed and seedling factors determine the ultimate number of seedlings produced.

Each year, as practices change, actual tree, yield, and damage percents should be calculated and any large changes from past years investigated as to cause. These new percents should be used as part of the updated data base for new seed- and seedling-requirement calculations.

5.5 Care of the Seedbed during Germination and Early Growth

A critical nursery period follows sowing. Seeds and seedlings are vulnerable to the environment and predators, and major losses can occur if seedbeds are not protected. If conditions are not right or care is not taken, viable seed either will not germinate or will be lost to predators or disease. Even after seedlings have emerged, predation and disease continue to be, problems. In addition, new seedlings may have to survive hail storms, scorching sun, and high temperatures. As spring progresses, weeds, if not checked, can reduce growth and even kill young seedlings by usurping water and sunlight. However, certain steps can be taken to nurture seedlings through this period and ensure their vigor.

5.5.1 Irrigation

After sowing, the soil surface should not be allowed to dry out. If soil becomes dry, the seed may dry too much, all advantages of stratification may be lost, and slow, spotty germination may result. Seed of species such as western hemlock *[Tsuga heterophylla* (Raf.) Sarg.], which are small and surface sown, are often covered with burlap to hold in moisture and prevent seed from being washed away. Careful watch must be kept daily because more than one watering per day may be required to maintain proper moisture status on spring days with high evaporative demand. As a rule, finer textured soils require more frequent watering than coarser textured ones (see chapter 12, this volume).

Too much water during germination, however, is not desirable. Excessive water promotes preemergence damping-off and growth of seed-borne fungi by decreasing soil temperature and increasing soil moisture [20]. A correct balance is important. If emergence is much slower than expected and examination of seed reveals that it is "rotting in the ground," decreasing water and spraying with an appropriate fungicide to prevent further damage can be beneficial.

After germination in the nursery has peaked, the watering regime should be changed. Frequent, shallow irrigation should be superseded by longer periods of irrigation. Soil should be kept between - 0.1 and - 0.75 bar at a depth of 15 cm (6 in.) for optimum growth and irrigated only when it approaches — 0.75 bar [8]. This regime is followed until hardening-off treatments are begun in midsummer (mid-July to mid-August). Predawn plant moisture stress is then allowed to increase to between 12 and 15 bars before rewatering to promote budset [7] (see chapter 15).

During the period from germination to dormancy, irrigation water is applied to cool and shade young (1+0), tender seedlings. In the exposed surface of a nursery bed, soil-surface temperatures can rapidly rise to over 45°C (112°F) on a warm, sunny day. This can literally "cook" the root-collar area and kill the seedling. To prevent damage, the soil surface can be cooled by irrigation.

Critical soil temperatures used for cooling vary with seedling age and species. Damage is most apt to occur in younger seedlings of species adapted to cool, moist climate; for instance, Douglas-fir and western hemlock are less tolerant to heat damage than most pines. Some. nurseries use air temperature as a guide for determining need for cooling, but the majority use soil-surface temperature, usually measured 0.5 to 1 cm below the surface. A typical guideline might be: irrigate when soil temperature exceeds 32°C (90°F) before July 1; 35°C (95°F) before August 1; and 38°C (100°F) until winter (composite from OSU Nursery Survey).

How long and how often a nursery applies water when critical temperatures are reached varies greatly and depends at least partially on soil type. Some nurseries irrigate 5 to 10 minutes during every hour the temperature is above that considered critical; others water for an hour; and still others water until the soil temperature drops below a fixed, safe temperature [e.g., 25°C (77°F)]. One nursery reported that due to its soil properties, irrigation does not reduce soil temperature but merely prevents further increase. Research data on critical temperatures and how they vary with the season for various species are not available. Therefore, nursery managers should adopt a reasonable schedule of cooling and adhere to it until sound research evidence produces a better one.

5.5.2 Diseases and insects

After emergence, damping-off can continue to be a problem (see chapter 19, this volume). Fumigation is the most common method used in the U.S. to rid the soil of damping-off fungi. In Canadian nurseries, where fumigation is not used, seed is covered with 0.5 cm of sand. This decreases the moisture around the seed and increases soil-surface temperature. No matter what is done to reduce occurrence of damping-off, it can still be a problem in certain years. Careful and frequent monitoring of the crop for any sign of disease and rapid treatment with a fungicide drench at the first sign can make a significant difference in tree percent.

Although not generally found in the Northwest (OSU Nursery Survey), insects can be a problem in the nursery. Cutworms probably pose the greatest threat. Patches of seedlings clipped just above the ground line soon after emergence can be a sign of this pest. Control can be achieved with a number of insecticides. Recently, another yet unidentified insect pest has caused extensive damage at nurseries in Oregon's Willamette Valley. Buds and stems of 1+0 and 2+0 seedlings have been damaged late in the growing season [pers. commun., 21].

5.5.3 Birds and rodents

As soon as the seed is sown and until the seedcoat is shed, birds can create a serious problem in the nursery. They seem particularly fond of pine seed and can destroy a crop in a very short time. In southern pine nurseries, seed is commonly coated with bird repellent. Northwest nurseries use either scare tactics or screening (OSU Nursery Survey). Where the problem is prevalent, owls painted on balloons, hawk decoys on posts, loud noises, and shotguns have all been tried, with varying degrees of success.

Screening is the most expensive and labor-intensive method, but also the most effective. A frame of wood as wide as the bed and 2 or 3 m long, covered with fiberglass screen, can be placed over the bed until seedcoats are shed. These frames are relatively inexpensive, reusable, and effective. Where possible, to reduce damage, nurseries can wait to sow until certain migratory birds have passed through their area. Rodents are generally not as great a problem but, where encountered, are usually controlled by poison bait and traps.

5.5.4 Weeds

The last pests to be considered, but the ones found most frequently, are weeds (see chapter 18, this volume). Recent developments in herbicides have made weed control easier and cheaper than ever before. As discussed previously, weed control begins when a field is selected for nursery production. As many weeds as possible, both in and around the field, are eliminated at that time. Where practiced, fumigation eliminates many residual seeds. Yet even with all this presowing care, weed seeds still blow into the nursery from surrounding fields and germinate if additional steps are not taken.

Most nurseries control weeds by applying a selective herbicide within a week after sowing. The most commonly used chemicals in Douglas-fir nurseries are oxyfluorfen (Goal 2E®) and bifenox (Modown®). Weed control usually begins to falter about midsummer and can be reinforced by a second application of herbicide or supplemental hand or machine weeding. Recent evidence that oxyfluorfen may limit germination of some conifer species and accumulates over time in some soils may cause reevaluation of its widespread use [unpubl. data, 22].

5.6 Conclusions and Recommendations

In seedbed preparation and sowing, planning is all-important. Many of the potential problems such as poor drainage, weeds, and disease can be eliminated or greatly ameliorated by careful planning and field pretreatment. The difference between a successful, economically run nursery and one that is continually trying to solve preventable problems at undue expense is planning.

Before preparing a new field for sowing, review the past history of the area; decide if any potential problems exist and how to eliminate them or at least alleviate their impact on the nursery crop. Determine an appropriate slope and orientation for the field. Before irrigation lines, roads, and beds are established, considerations of field efficiency should be balanced with those of ease of operation. Once irrigation lines are established, it is almost impossible to improve field efficiency.

Beds should be raised 6 to 12 cm above ground level and have smooth, even surfaces; this allows more uniform sowing. Seed should be sown as early as possible in spring, after the soil temperature at the 10-cm depth exceeds 10°C. Most commercially available seeders do an adequate job of distributing seed, although the Øyjörd is generally more versatile. Sowing depth should be uniform for uniform germination. A sowing depth of "just covered" to 0.5 cm is recommended for Douglas-fir.

Sowing density and subsequent growing density have a pronounced effect on the resulting size of the seedling and its production cost. Managers should consider growth characteristics in the nursery and costs of various nursery operations when determining rowing density. A growing density of 160 to 325 seedlings/m^2 (15 to 30 seedlings/ft^2) is recommended for 2+0 Douglas-fir.

In addition to planning, crop monitoring and recordkeeping are necessary to obtain the numbers needed for a viable sowing formula. Accurate tree, yield, and damage percents are essential to determining the correct amount of seed and bed space to grow a given seedlot.

Proper care and tending after sowing ensure the early success of the crop. The secret is to be aware of the possible problems and keep a constant vigil. Diseases, birds, weather, and weeds are the most common causes of loss.

Although a vigorously growing 1 +0 crop free from weeds and pests is the goal of all nurseries, many factors may combine to make this difficult to achieve. Bareroot nurseries are always at the mercy of nature. Hail, excessive rain, and cloudy or hot weather all take their toll. It is important, therefore, that nursery managers understand and optimize all those factors over which they exert a measure of control. Good seedbed preparation and sowing practices and early seedling care all increase the likelihood of success. Having accepted the challenge of growing seedlings and succeeded, nursery managers and personnel may find nothing more beautiful than looking over their fields of lush green, uniform, healthy seedlings.

References

1. Aldhous, J. R. 1972. Nursery practice. Her Majesty's Stationery Office. London. Forestry Commun. Bull. 43. 184 p.
2. Armson, K. A., and V. Sadreika. 1979. Forest tree nursery soil management and related practices. Ontario Ministry of Natural Resources. Toronto. 179 p.
3. Arnold, E. W. 1972. Effect of sowing accuracy on seedling-size 1-0 and 2-0 Douglas-fir. Weyerhaeuser Washington Nursery. Pages 20-29 in Proc. (H. W. Anderson, J. A. Bryan, and R. P. Eide, eds.). Western Forest Nursery Council and Intermountain Forest Nurserymen's Assoc., Olympia. Washington.
4. Baron, F. J., and G. H. Schubert. 1963. Seedbed density and pine seedling grades in California nurseries. U.S.D.A. Forest Serv., Pacific SW Forest and Range Exp. Sta., Berkeley, California. Res. Note PSW-3 l . 14 p.
5. Bunting, W. R. 1980. Seedling quality: growth and development—soil relationships, seedling growth and development, density control relationships. Pages 21-42 *in* Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
6. Campagna, J. P., and D. P. White. 1973. Nursery soil fumigation affects growth and phosphorus nutrition of pine and spruce seedlings. Forestry Chronicle 49:219-223.
7. Cleary, B. D., and J. B. Zaerr. 1980. Pressure chamber techniques for monitoring and evaluating seedling water status. New Zealand J. Forestry Sci. 10(1):133-141.
8. Day, R. J. 1980. Effective nursery irrigation depends on regulation of soil moisture and aeration. Pages 52-71 *in* Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
9. Edgren, J. W. 1976. Seedbed density, diameter limit culling and 2-0 Douglas-fir seedling production. Proc., Western Forest Nursery Council and Intermountain Forest Nurserymen's Assoc., Richmond, B.C. 9 p.
10. Hart, J. B., Jr. 1980. Basic nursery soil physical properties. Pages 44-51 in Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
11. lverspn, R. D. 1981. Low bed densities enhance Douglas-fir seedling size and performance. International Paper Co., Western Forest Res. Center, Lebanon, Oregon. Tech. Note 60. 6 p.
12. Krugman, S. L., and J. L. Jenkinson. 1974. *Pinus* L. Pine. Pages 598-638 in Seeds of woody plants in the United States. U.S. Dep. Agric., Washington, D.C. Agric. Handb. 450.
13. Lott, J. R., and B. J. Lowman. 1976. Evaluating precision seeders for tree seedling nurseries. Report ED&T 2522. U.S.D.A. Forest Serv. Equipment Development Center, Missoula, Montana. 49 p.
14. May, J. T. 1982. Seed preparation. In Southern pine nursery handbook (C. Lantz, ed.). (In press.)
15. Owston, P. W., and W. I. Stein. 1974. *Pseudotsuga* Carr. Douglas-fir. Pages 674-683 *in* Seeds of woody plants in the United States. U.S. Dep. Agric., Washington, D.C. Agric. Handb. 450.
16. Pair, C. H., W. W. Hinz, C. Reid, and K. R. Frost. 1975. Sprinkler irrigation. Irrigation Assoc., Silver Spring, Maryland. 615 p.
17. Rowan, S. J. 1980. Planting depth and seedbed mulch affect germination of slash pine seed. U.S.D.A. Forest Serv., Southeastern Forest Exp. Sta., Asheville, North Carolina. Res. Note SE-292.3 p.
18. Shearer, M. N. 1980. Requirements for quality irrigation. Pages 107-112 *in* Proc., Joint meeting, Intermountain Forest Nurserymen's Assoc. and Western Forest Nursery Council, Boise, Idaho.
19. Sorensen, F. C. 1978. Date of sowing and nursery growth of provenance of Pseudotsuga menziesii given two fertilizer regimes. J. Applied Ecology l 5:273-280.
20. Sutherland, J. R., and R. L. Anderson. 1980. Seedling disease and insect problems related to nursery soil conditions in North America. Pages 182-190 in North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
21. Tanaka, Y. 1982. Personal communication, Weyerhaeuser Co., Centralia, Washington.
22. Thompson, B. 1982. Unpublished data, International Paper Co., Lebanon, Oregon.
23. van den Driessche, R. 1979. Soil management in Douglas-fir nurseries. Pages 278-292 *in* Forest soils of the Douglas-fir region (P. E. Heilman, H. W. Anderson, and D. M. Baumgartner, eds.). Washington State Univ. Ext. Serv.. Pullman.
24. Whalen, M. 1981. Personal communication, Weedco, Portland, Oregon.
25. Wilson, B. C., and R. K. Campbell. 1972. Seedbed density influences height, diameter and dry weight of 3-0 Douglas-fir. Tree Planters' Notes 23(2):1-4.